

CP 170-25634

NASA TECHNICAL TRANSLATION

NASA TT F - 12,741

NASA TT F - 12,741

Page One Title

Cover SPACE

V. G. Kuznetsov

Science in the Year 2000 (Nauka v 2000 Godu) "Nauka" Press,
Moscow, pp. 171-190, 1969

CASE FILE
COPY



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

APRIL 1970

SPACE

V. G. Kuznetsov

Cover Page Title

ABSTRACT. Discussions of various theories of the evolution of the universe are followed by predictions that certain events of importance in astronomy and astrophysics will take place before the year 2000, including observations from the surface or from the vicinity of planets of the earth group, and the use of nuclear energy in space probes. It is predicted that solutions will be found for such problems as the nature of the expanding universe as well as for other problems related to various theories pertaining to the origin and evolution of the universe. The new astronomical revolution which began in the XX century will lead to a confirmation and specific definition of relativistic cosmology.

One of the most outstanding statements of the theory of relativity, contained in the book written in 1923 by A. A. Fridman, "The Universe as Space and Time," was prefaced by the author in the form of an epigraph of the following extract from "The Historical Materials of Fedot Kuz'mich Prutkov":
"Once, when the night covered the heavens with its mantle, the French philosopher Descartes, who was sitting on his stairstep and was regarding the gloomy horizon with great attention, was approached by a passerby with the question: *"Tell me, wise man, how many stars are in the sky?"* *"You good for nothing!,*" he answered, *"No one can comprehend the incomprehensible!"* These words, pronounced with great force, had the desired effect on the passerby." /171*

In the first lines of the book following the epigraph, A. A. Fridman says that "Among thinking humanity we shall always find curious passersby and more well-mannered wise men than Descartes, who attempt, on the basis of insignificant data, to create a picture of the universe." [1] In the remaining decades of the XX century these well-mannered wise men will be able to respond to questions of curious passersby about the universe, based on data which is no longer quite so insignificant. But the matter no longer concerns calculations concerning discrete bodies in the universe alone. The space problem is

*Numbers in the margin indicate pagination in the foreign text.

no longer and perhaps not so much a problem of interacting discrete bodies as /172
it is a problem of fields which differ in nature. The most significant distinction consists of the fact that now it is impossible without any theoretical constructions which encompass the metagalaxy as a whole to advance with sufficient rapidity in those fundamental fields of science which give to our era its characteristic dynamism.

The classic picture of interacting bodies--of the stars, planets and comets--was the result of the first astronomical revolution, brought about by the telescope. When in 1610 Galileo directed his telescope toward the sky and detected the discrete nature of the Milky Way and other previously unknown facts and published his discoveries in "The Stellar Ambassador," a period began of proof, theoretical thought and specific definition of the Copernican system--of the picture of interacting bodies without the "natural movements" of Peritattetic cosmology.

The new astronomical revolution which began in the middle of the XX century and which continues now and has every chance of encompassing the end of the century, and perhaps even the beginning of the next century, will apparently lead to the confirmation and specific definition of relativistic cosmology, i.e., to a picture of space which is curved, and the radius of which changes with the passage of time. In this connection the new astronomical revolution permits us to see in this space the play of interacting fields, the existence and behavior of the quanta of these fields and of elementary particles.

The second astronomical revolution takes as the most general basic idea the relativistic model of the metagalaxy and attempts to associate it not only with gravitation but also with different types of fields. If we speak of observational facilities then the initial point of a new astronomical revolution is made up, first of all, of observations from satellites and space probes and secondly of the replacement, or to be more exact, the supplementing of the human eye by astrophysical instruments which detect electromagnetic waves not only in the optical but also in other ranges, as well as the flows of various particles in addition to electromagnetic radiation.

Artificial earth satellites and space ships have already permitted us to.

observe the radiation of astronomical objects with no hindrance from the earth's atmosphere on these observations. A quite reliable prediction for the year 2000 promises observations from the surface of the moon and from the surface or from close orbits surrounding Mercury, Venus and Mars. The possibility of delivering astronomical and astrophysical instruments to planets of the earth group is the fundamental point of predictions for the development of astronomy for the year 2000. Space rockets at the present time still do not employ nuclear energy. But such use is foreseen in predictions for the year 2000. In this sense astronautics, which now has its own independent power base (therefore it is valid to add "space" in the oft-repeated characterization "atomic-space era"), as a result will experience the resonance effect of nuclear power and will depend on its progress. /173

There is still another and significantly more subtle relationship between the prospects of astronomy and nuclear physics. This concerns nuclear reactions known to the physicist which draw for explanation upon the results of astrophysical observations.

The transfer of nuclear models from the microcosm to stellar astronomy furnishes particularly important results when we speak of the so-called *main sequence* of the stars. This term, which was introduced by Eddington, is defined as follows.

Stars consist mainly of plasma--of hydrogen nuclei, i.e., of protons and helium nuclei, mixed with electrons torn from them. In addition, stars also have in comparatively small numbers the nuclei of heavier elements--of oxygen, nitrogen, carbon, iron and several others. Stars belong to different spectral classes; they are distinguished by color. The color depends on temperature and may be reddish, yellowish and at the very highest temperatures, white and bluish. On the other hand, stars are also distinguished by luminosity (i.e., by the quantity of energy radiated by the star per unit time). Luminosity is associated with the apparent brightness of a star; the latter depends also on distance and if all stars are reduced to an arbitrary standard distance the luminosity will be a measure of absolute stellar magnitude. Stellar radii change within very wide limits: there are stars no larger than the earth ("white dwarfs"), while others occupy a space which is sufficient not only /174

for the sun, but also for the orbit of the planets of the earth group. Mass shows less change since large stars may be billions of times less dense than small stars.

For most stars luminosity and color coincide: if along the horizontal axis from the left to the right we place the spectral classes which correspond to decreasing stellar temperature, and we place increasing luminosity values along the vertical axis from the bottom to the top, we see that most stars fall along the diagonal which passes from the upper left corner (i.e., from the region of high luminosities and high temperatures) to the lower right corner (i.e., to the region of low luminosities and low temperatures). This is the "main sequence" of stars: on the diagram luminosity decreases with a reduction in the temperature of stars and with a change in their color from blue and white to yellow and then to red.

Outside the main sequence we find stars with very high luminosity ("giants" and "super giants"), but which belong to a spectral class which coincides with a comparatively low temperature; they are distinguished by a reddish (sometimes by a yellowish) color and are called red giants. Also outside the main sequence on the diagram is the group of stars of high spectral class with comparatively low luminosity ("white dwarfs").

The evolution of stars in the main sequence is explained by the course of nuclear processes. The basic source of stellar energy is the thermonuclear reaction, the formation of helium nuclei from protons. The stellar period on the main sequence agrees with the specific effect of the thermonuclear reaction on stellar radiation. The evolution of a star in the main sequence, i.e., the spectral change in its radiation and corresponding change (this correspondence also means that the star remains in the main sequence) in luminosity has the following significance, in the light of nuclear physics [2].

Let us assume that interstellar material began to condense and then under the influence of gravity the primary cloud formed a nontransparent, gaseous sphere. /175

Gravitational forces compress this sphere, its temperature increases, but it is still not large and therefore the star color approaches red;

luminosity, which depends on mass, may be very high. Subsequent gravitational compression increases the temperature, the star color begins to correspond to its luminosity, and the star proves to be in the main sequence. Now the star temperature permits the thermonuclear reaction to begin and this reaction in turn maintains the temperature, and therefore also the radiation spectrum of the star at a slowly changing level. The star luminosity also changes slowly. If the mass is high and the radiation is quite intensive (as for "blue giants"), in the course of several million years the star loses its hydrogen reserves, the protons are converted comparatively rapidly into helium nuclei and the star becomes a helium sphere, the luminosity of which no longer corresponds to its spectrum. But soon (on the space time scale) a new nuclear reaction begins. Three helium nuclei are transformed into a hydrogen nucleus. If the temperature continues to be high other thermal reactions may also occur which terminate with the formation of iron, which is then incapable of participating in nuclear reactions with the release of energy. For a star with a mass approaching that of the sun the entire evolutionary process may continue for about 10 billion years.

Such calculations are directly associated with nuclear physics and are quite characteristic for atomic age science. The basis of these calculations consists of concepts concerning nuclear reactions which thus far have not been applied in practice but which serve as the basic object of experimental and theoretical investigations. But here another aspect of the atomic era exerts an influence. Star evolution may be expressed in quantitative definitions, while the periods of evolutionary stages, temperatures, radii, luminosities and star spectra may be expressed only with the aid of electronic computers.

For stars with a mass which approaches that of the sun, i.e., those with a lesser mass or a somewhat greater mass (up to 1.2 times the mass of the sun), the last stages of this biography consist of transformation into "white dwarfs" and of subsequent cooling. Their mass remains the same--of the order of the mass of the sun, while dimensions are significantly reduced and approach those of the earth. In this case density attains values of tens of tons per cubic centimeter. Such a fate may also befall a "red giant," if it

throws off its mantle and reveals an incandescent nucleus (i.e., if it passes to another spectral class) and reduces its mass.

"White dwarfs" may exist for an extended period of time, i.e., for billions of years, while gradually cooling and being transformed into "black dwarfs," which do not radiate at all. The comparative stability of "white dwarfs" is explained by purely quantum regularities. Thermonuclear reactions which release large quantities of energy no longer occur in the "white dwarf." The exhaustion of the nuclear fuel disturbs the balance which is characteristic of the main sequence between gravitational compression and the pressure of incandescent plasma particles. But here the principal revealed by Pauli plays a part, in that two electrons are forbidden to be in the same state. With high density of the plasma which consists of nuclei and electrons, electrons with identical velocity are very close to each other and the Pauli exclusion is expressed in their mutual "repulsion"--in the elasticity of the electron gas¹.

We have spoken above concerning the origin of stars from diffused, scattered matter as the initial step in their evolution. Another concept also exists which states that the stars were formed from dense bodies [3]. This concept, developed by V. A. Ambartsumyan and his school, has a high "prediction importance"; there is some justification for assuming that this concept will acquire new arguments during the course of the years and decades of the near future.

The theory of the evolution of stars is based on the theory of nuclear reactions and on the theory of gravitation. As long as we are examining the main sequence and preceding stages of evolution, we are concerned with gravitation as described by Newton's theory. But gravitational processes exist which by nature may go beyond the framework of Newtonian theory. These processes break through the normal and "ordinary" (i.e., subordinate to Newtonian law) gravitational forces of stellar evolution, associated with nuclear reactions. In connection with similar cataclysms a star, in the /177

¹See the description of this situation and of stellar evolution as a whole in the article by I. D. Novikov, "The Final Fate of the Stars" (Reference manual "Future Science," 2nd Edition, Moscow, 1968, pp. 111-123).

course of a short time, radiates more energy than billions of stars, than an entire galaxy. Such processes perhaps serve as the reason for calling these outbursts supernovae [4].

New stars flare up frequently--nearly 100 per year in the galaxy, while supernovae appear in large galaxies on the average of once in the course of a century. In our galaxy the last supernova occurred in 1604. Now, when it is possible to observe a multitude of galaxies (in connection with which not only optical radiation can be perceived and measured), sufficient observations have been accumulated which clarify the nature of supernovae. It is possible to believe that supernovae sometimes appear from stars which have already undergone an extensive evolution, and sometimes from young, extremely massive stars which exceed the mass of the sun by two times or more. Upon flareup they form gaseous nebulae which are characterized by a high degree of radio activity and powerful optical and X-ray radiation. V. L. Ginzburg and I. S. Shklovskiy believe the supernova outbursts to be the main source of cosmic rays. The problem of the origin of cosmic rays is one of the main astrophysical problems for which solutions must be projected for the end of the century. In this respect extraterrestrial observations from space probes, from the lunar surface and from the planets of the earth group will allow a more exact determination of the composition of primary cosmic rays, while yet unchanged by interaction with the earth's atmosphere.

The nature of supernovae is still far from clear and everything that is said about this subject now represents only initial hypotheses which illustrate the nature of the astrophysical problems which will be solved at the end of the century. It is possible that during the course of this time the concept will be confirmed concerning an explosion caused by gravitational compression under the influence of forces which correspond to Einstein's law of gravitation./178 This idea is quite characteristic of contemporary astrophysics, of its tendencies and prospects.

We have already spoke of "white dwarfs," i.e., of the comparatively stable final states of stars with a mass not greater than 1.2 times the mass of the sun. For stars with large mass, electron gas pressure is insufficient to oppose gravitational compression; the latter continues to act and the star is

reduced to dimensions of the order of 10 km, while acquiring fantastic density which exceeds the density of the atomic nucleus, i.e., 100 billion tons per cubic centimeter. In connection with this density the free electrons combine with protons, the protons capture them and are converted into neutrons; the star then consists of closely compressed neutrons. In this overdense state complex atomic nuclei no longer exist. Then only elementary particles heavier than nucleons may exist; these particles do not disintegrate under such high density.

Within specific limits the elasticity of overdense matter may oppose further gravitational compression. If a neutron star did not exceed in mass twice the mass of the sun or lost its excess mass, it would gradually cool. At the present time the existence of neutron stars has not been proved. Included among the forthcoming possible discoveries in the predictions of astrophysics are discoveries of neutron stars in connection with neutrino observations, i.e., of uncharged particles with zero rest mass, the radiation of which must accompany hypothetical reactions in these stars. Perhaps neutron stars will be detected by their X-ray radiation [5].

A neutron star with a mass not exceeding two times the mass of the sun is first included among the cooling and then among the cooled stars and this is the final point in its evolution. For this mass of the star after disruption of the balance between elasticity due to nuclear reactions and gravitational compression is greater than the indicated value, the elasticity of the compressed and neutron-rich substance do not stop gravitational compression which in this case acquires the nature of a cosmic catastrophe. /179

Catastrophically rapid compression is called *gravitational collapse*. This term is already familiar to us for gravitational collapse was encountered in connection with the hypothesis of maximums. This concerns star compression under the influence of gravitational forces which develop in accordance with Einstein's law of gravitation. In accordance with Newton's law, gravity increases without limit when the distance between bodies approaches zero. On the surface of the star the gravitational forces approach infinity when the star contracts to a point, i.e., its dimensions approach zero. According to Einstein's law, gravity approaches infinity when the radius of the star

approaches a definite value which is proportional to its mass. For the sun or for another star with the same mass this radius equals three kilometers. Here, at this distance from the center of the star, the gravitational forces become infinite and the rate of convergence of the particles under the influence of these forces becomes equal to the velocity of light. An extremely paradoxical picture follows for this case from the theory of relativity. It would seem that a body in motion in such a gravitational field would cover a tremendous difference in the course of a brief instant. But this "brief instant" in the theory of relativity loses absolute meaning. The expression "brief instant" has meaning for a system of reference fixed on the star itself. For other systems, for example, for our earth system of reference, this instant becomes an increasing time interval in proportion to the progress of compression, and when this brings the star to the critical radius already mentioned, the instant is infinitely extended.

The general theory of relativity examines gravitation as a change in the space-time metric. The greater the gravitational field stress at a given point, the greater the change in the metric, and thus the longer becomes a second measured at this point if we convert to another coordinate system and measure this second there. In a star system that which lasts for a second in another coordinate system may prove to be an hour, a century, one thousand years or a billion years. In connection with star compression to the critical radius indicated above, any time interval becomes infinite in another reference system free from such an intensive gravitational field. The increase in time intervals in a gravitational field is expressed, in particular, in an increase in the period of electromagnetic oscillations and correspondingly by an increase in the length of electromagnetic waves and in a red shift of spectral lines. A gravitational field corresponding to star compression to the critical radius (which is proportional, as we have already mentioned, to the mass of the star and for the mass of the sun equals 3 km) converts the periods of the electromagnetic oscillations to infinite periods. This means that electromagnetic radiation ceases. All radiation ceases. The collapsing star is associated with other bodies only by gravitation. The star falls, in the expression by Ya. B. Zel'dovich, into a gravitational grave.

/180

Gravitational collapse belongs to a number of processes which differ principally from ordinary relativistic processes (here the word "ordinary" designates "comparatively known to science, serving the basic object of investigation and applied in practice"). These ordinary relativistic processes require for their description consideration for the relationships of the theory of relativity because released and absorbed energies are compared with the rest masses of particles multiplied by the square of the speed of light. Ultrarelativistic processes, beginning with the discoveries at the beginning of the 1930's of annihilation and generation of electron-positron pairs, are associated with the absorption and release of energies of the order of the rest mass, multiplied by the square of the speed of light. The study of such processes brings science closer to a solution of the most fundamental problems for our time de rerum natura, and facilitates the practical application of these processes and the transition to an ultrarelativistic civilization--the embodiment of subnuclear physics.

In contrast to ordinary evolution (in the meaning indicated above) in the main sequence, where gravitational compression is balanced by thermonuclear and nuclear reactions in general, the debut and the finale in the life of stars approach the full realization of the equation $E = mc^2$, i.e., to the full transformation of potential energy into radiation energy. Under conditions of ultrahigh pressures involving density greater than the density of the atomic nucleus, and concentration of the entire mass of the star in a sphere with a radius of several kilometers with infinite (for the external observer) length of radiated waves in this world of the collapsing star, certain processes occur on subnuclear scales which are still not clear. A picture of these processes cannot be drawn if we are limited by the special theory of relativity. Here gravitation encroaches upon the microcosm. In connection with the tremendous density of matter which is only encountered here in collapsing stars, in the small distances between particles, the gravitational relationships which are very weak by the ordinary scales of atomic physics become quite intensive. Therefore in order to understand these processes a certain synthesis is required between the quantum physics of the microcosm and the general theory of relativity, i.e., the contemporary theory of gravitation. /181

Thus the final fate of the stars depends mainly on their mass: stars with a mass of less than 1.2 times the mass of the sun become white dwarfs; stars with a mass of 1.2 to 2 times the mass of the sun are transformed into neutron stars; stars with a mass which is greater than twice that of the sun collapse and fall into the "gravitational grave." In the process of revolution loss of the mantle is possible with a reduction in mass and a corresponding change in eventual fate. A characteristic feature of contemporary astronomy and astrophysics is the close relationship between problems of stellar evolution and problems of galactic evolution. Stars form from interstellar matter and they themselves are the source of replenishment of stellar matter during cataclysms which strip away stellar mantles. But this desire leads to a conclusion of a diminishing quantity of interstellar matter in the galaxy. Part of this matter remains in stable dwarfs which conclude the main sequence and another part remains in slowly evolving stars which do not exceed in mass 1.2 times the mass of the sun and are not able during the time of existence of the galaxy to complete their evolution. This is the first conclusion concerning the balance of the galaxy from the plan of stellar evolution. It refers to the distribution of matter among stars and interstellar gas. The problem of the origin of heavy nuclei follows from this plan of stellar evolution. The initial supply of hydrogen is gradually consumed in the formation of helium. Oxygen and carbon are formed from the helium. But at a certain stage the further accumulation of nucleons in the nuclei ceases, since new nuclei proved to be unstable and disintegrate before they are joined by new nucleons. It may be assumed that the situation is different during eruptions which we call supernova outbursts. During the chain reactions which occur here numerous neutrons appear which are captured by nuclei before their disintegration. After capture of the neutrons these nuclei become stable and the increase in the number of nucleons, i.e., the transition to heavier elements occurs without hindrance as far as those elements which are at the very end of the Mendeleev table. During outbursts of supernovae heavy nuclei penetrate the interstellar gas and subsequently into the second-generation stars which are formed from the gas.

The following picture is drawn of the origin of the galaxy, i.e., of events which occurred 10-15 billion years ago. The initial plasma cloud,

/182

consisting mainly (or perhaps completely) of protons and electrons, was compressed under gravitational influence. Condensation of the primary cloud occurred nonuniformly, and local coagulations occurred from which stellar clusters were later formed; lesser coagulations within the limits of these first coagulations were the future stars of the first generation. The cloud became a protogalaxy. It rotated, which prevented the gravitational attraction of all plasma in the center; this was concentrated in the plane perpendicular to the rotational axis.

Phenomena are known to contemporary astronomy which require further analysis of the evolution of the galaxy for their explanation. There is a basis for believing that the gradual transition from a primary proton-electron cloud to a protogalaxy and then to the stellar galaxy has been interrupted, and perhaps powerful explosions in the galactic centers are occurring which are incomparably more powerful than the outbursts of supernovae. In addition to the nebulae in the composition of our galaxy, which are due to outbursts of supernovae and which possess very intensive radio-frequency radiation, there exists very far from us galaxies with intensive radio-frequency radiation. It is possible that these *radio galaxies* originated from astronomical objects similar to those which were discovered at the boundaries of that part of the universe known to us. They are called superstars, quasi-stellar objects, quasi-stars or *quasars*. It is possible to determine distances to the quasars from red shift, and therefore from recession velocity; having compared this distance with the apparent brightness, we evaluate their luminosity. It may be concluded from this that the light from quasars which reaches us now was radiated several billion years ago. A present-day quasar, if it exists now, may be seen on the earth in many billions of years if by this time the earth, the solar system as a whole, and our galaxy are still in existence.

What the quasar represents is not known at the present time. Its luminosity, if we keep in mind the observed brightness and the tremendous distance, exceeds by 100 times the luminosity of the most prominent of the galaxies known to us. The source of such energy may be gravitational compression or thermonuclear reactions (proposals have been expressed concerning

a chain reaction of outbursts of supernovae, as well as the explosion of a massive gaseous sphere, formed in the galactic center, i.e., a star several million times greater than the sun).

The farther a certain galaxy is located from us the greater its recession velocity and the greater the red shift. This reduces the apparent brightness of distant galaxies. Such brightness attenuation within certain limits is compensated for by the construction of very powerful telescopes in the optical, infrared and radio bands and in the future by situating such telescopes on artificial satellites and on the moon. In the more distant future they will also be situated on the planets of the earth group and on satellites of these planets. We may be assured that in the course of the decades which separate us from the year 2000, even more distant objects will be discovered which perhaps will prove to be more prominent and more enigmatic than quasars.

Distant astronomical objects are located at great distances from us, but we study them as they were billions of years ago when they sent out the light which reaches us now. Therefore observations of quasars may lead to very radical cosmological conclusions and to new concepts concerning the evolution of the universe. Here it is possible to see a characteristic peculiarity of scientific predictions. The enumeration of astronomical and astrophysical problems (the evolution of the stars, neutron stars, supernovae, collapse, the origin of cosmic rays, the nature of quasars) represents in essence a prediction design for the decades immediately ahead: we assume that during this period problems will be solved to a certain extent which were posed by the discovery of supernovae, quasars, etc. In contemporary astrophysics almost each generalization, almost every new concept and almost every significant result of observation represent not only hypothetical statements which pertain to the structure of the universe, but also hypothetical statements concerning that development of astrophysics and astronomy which confirms and specifically defines an expressed hypothesis or forces its refutation. Therefore the enumeration of problems and hypotheses in contemporary astrophysics and astronomy represents a certain diagrammatic prediction of the development of science itself.

This prediction issues from observations already made, concepts already

/184

expressed and problems already formulated. In addition, any prediction in this area involves the inevitability of new observations and fundamentally new results. A similar inevitability is the such an inevitability is the authentic component of the prediction, although it does not permit specific interpretation. We have really only entered upon the era of extraterrestrial observations and the study of nonoptical bands. New observations will certainly raise new problems and will change the development of astrophysics and astronomy.

We are again convinced that scientific prediction represents in a general case a tangent to a real curve, a tangent which shows the direction of a curve which may change at any moment. This in no way changes the significance of predictions--neither theoretically nor practically. In contemporary science the hypothesis more than at any other time is a condition of progress for authentic positive knowledge. In the physics of elementary particles the contemporary period is a period of reasoning out questions which will be put to nature with the help of a new generation of expeditors. In astrophysics the contemporary period demands the reasoning out of questions which will be put to nature with the help of telescopes and astrophysical radiation receivers on satellites, on the moon and subsequently on the planets of the earth group. To a great extent the questions in the theory of elementary particles and questions of astrophysics coincide. Both however are prepared in the form of physical and astrophysical hypotheses which in addition serve as unique predictions of scientific development. As far as the practical effect of these hypotheses and predictions are concerned, they raise the intellectual potential of science and this affects the qualitatively indeterminate but undoubted acceleration in the progress of civilization. In order to raise the intellectual potential of science a great deal of significance is attached to the unavoidable appeal to general cosmologic hypotheses during the development of large-scale particular astronomical and astrophysical problems. Of a large number of cardinal questions concerning the structure and evolution of the universe as a whole, we shall examine the questions:

- 1) Concerning the homogeneity of the universe; 2) Concerning its finiteness or infinity; 3) Concerning expansion of the universe; 4) Concerning its state prior to expansion and 5) Concerning the symmetry or asymmetry of the universe

/185

in the sense of equal or unequal content of particles and antiparticles.

A first glance at the sky detects the nonuniformity of mass distribution. In stars matter differs sharply in density from the interstellar medium.

Stars are grouped in galaxies where the average density is naturally greater than in intergalactic space. The sun belongs to a galaxy which consists of 100 billion stars. Beyond this there is starless space and then new galaxies, located at distances of 1-5 million light years. Occupying even greater expanses, we detect clusters which consist of tens or hundreds of galaxies.

But we do not detect larger structural units. Therefore it is permissible to assume that the universe, taken in scales which we encompass with the telescope, is homogeneous. In passing to greater scales, we obtain at the boundary the same density of matter, regardless of where the stellar sky observation is made. For a sphere with a radius of about 3 billion light years, where hundreds of millions of galaxies are located, the average density approaches 10^{-30} g per cubic centimeter. We may examine the matter within these limits as a certain cosmic uniformity substratum, while ignoring local nonuniformities clear up to clusters of galaxies. The distances between such clusters become very small in comparison with the sphere which encompasses that part of the universe known to us. We may assume that the universe is homogeneous in expanses which are still inaccessible to the telescope.

A certain "optical horizon" exists beyond which we are still unable to see, because objects are located there (if the picture is simplified somewhat) which recede from us at the speed of light; in this connection the red shift becomes infinite and these objects are not visible. But at significantly shorter distances the postulate of homogeneity in the universe is a question which can be confirmed by observations. The scope of the universe investigated, for which its homogeneity is confirmed by observations, depends (within the limits indicated) on the power of telescopes, of their location outside the terrestrial atmosphere and on the possibility of intercepting all bands of electromagnetic waves and all types of cosmic radiation, or in other words, on the course of the new astronomical revolution. As we shall see, answers to other fundamental cosmological questions also depends on this revolution.

These include the question of the finiteness or the infinity of the

universe. Here we must return to the brief remarks concerning the general theory of relativity made at the beginning of this book and develop them somewhat. Einstein examines gravitation as a change in metrics, as a transition from Euclidean properties of space-time to non-Euclidean properties, as a curve in space-time. Moving in space, we shall encounter local gravitational fields of planets, stars, galaxies, i.e., space-time curves which force the world line of a body to curve, similar to the manner in which on the two-dimensional surface of the earth mounds, knolls, hills and mountains curve the trajectory of a body moving over the terrestrial surface. But on the earth, in addition to these local curves, the general curvature of the planetary surface also exists. Aside from local gravitational fields does not a curve exist in the universe similar to the overall curvature? If space-time as a whole possesses such a curvature, the motion of a body, having flown through space from a given point at a given moment, would terminate the flight at the same point and at the same time; its world line would be closed, just as the trip is closed of a round-the-world traveler, who set out along the surface of the earth, not changing direction. But a closed line in space does not contradict the axioms of physics, whereas a closed world line and the arrival of a space traveler at the same point and at the same time that he set out on his trip are physically impossible. Einstein therefore proposed that time is not curved but that only space possesses the curvature. A body which freely flies in the universe, regardless of the local fields which change its direction, will fall at the same point, having described a closed line the length of which depends on the space curvature. But this will occur in billions of years and a return to the same instant will not occur. A similar structure of a four-dimensional world which involves spatial dimensions which possess a curvature, while time does not possess a curvature, reminds one of a cylinder the surface of which is straight in one dimension (parallel to the axis) and curved in the other, transverse direction. The world of Einstein is therefore called a cylindrical world.

/187

This is a closed model of the universe. It has finite volume and the trajectory of a freely moving body within it cannot be infinite. But such a finite universe does not resemble the finite universe of Aristotle; here there is no boundary which closes the universe. It also does not resemble the model

of a stellar island in a boundless ocean of empty space. Here the ocean itself, although it has no shores, is limited. If we pass from three-dimensional space to a two-dimensional surface, it is easy to find a visual representation; the surface of a sphere has no boundaries but it is finite in area and it is impossible to draw on it a geodetic line of unlimited length.

A similar concept concerning outer space is not uniquely possible. Here space becomes a spherical surface and the geometry of the universe is the geometry of Riemann: through a point outside a line, not one line can be drawn which will not intersect the given line; the sum of the angles of a triangle is greater than two right angles; perpendiculars to the same straight line intersect, etc. But it cannot be excluded that the geometry of the universe is different. It is possible to imagine a curved surface of the saddle surface type and to be convinced that the geometry of Lobachevsky is realized on it: through a point outside a line it is possible to draw as many lines as desired which do not intersect the given line; the sum of the angles of a triangle are less than two right angles; perpendiculars to the same line diverge. If outer space is a three-dimensional analog of such a surface, then it is open. It is open if space curvature does not exist, if its two-dimensional analog is a plane.

/188

If the universe possesses a certain space curvature, it may be constant or it may depend on time. The second assumption forms the basis for the oft-noted models advanced by A. A. Fridman in 1922, models of an expanding universe. We already know that the red shift detected due to the spectra of distant stars confirmed the Fridman model. The question of the nature of the expanding universe is an open one. It is not possible to say now whether the expansion occurs as an irreversible process or whether the universe pulsates and expansion will sometime be replaced by compression. The solution of this problem depends on data concerning the average density of matter in the universe and in general on the results of astronomical and astrophysical observations. It may be assumed that a unique solution will be found to the problem in the last third of our century, i.e., before the year 2000.

From the course of the new astronomical revolution we may also expect

in this period an answer to another cardinal cosmologic and cosmogonic question. This is the question of the state of the universe at the time when it began to expand.

If we proceed from modern concepts concerning the rate of expansion we find that 7-14 billion years ago the universe was an overdense body. What was its temperature? In 1946 Gamow advanced the model of a "hot universe"--the assumption of a very high initial temperature. When the expansion of the universe brought it to an average density equal to the density of the center, the temperature was approximately 10^{13} degrees, while previously at a higher density, the temperature was even higher.

Data for a certain solution of the problem concerning the initial state of the universe are closely associated with astrophysical observations and even with works which have a practical effect. During a study of radio noise in 1965 at Bell laboratories, thermal radiation was discovered which reaches the earth from all sides with the same intensity. From the nature of this "relic" radiation the existence was derived of a certain specified temperature in intergalactic space and its value was linked with the initial temperature of the universe, as evaluated by the "hot" model. Numerous works associating this model with astrophysical data are based on the transmutation of elementary particles (in particular, on the annihilation of heavy particles and the preservation of the neutrino and several other particles).

The problem of the symmetry of the universe is just as closely associated with the theory of elementary particles. In the theory of elementary particles we examine *matter* (electrons, protons, neutrons, etc.) and *antimatter* (positrons, antiprotons, antineutrons, etc.) Is the universe symmetrical in the sense that matter and antimatter are represented in it in quantitatively equal shares? Theories exist which derive from the newest hypotheses concerning elementary particles of asymmetry of the universe--a lack of macroscopic concentrations of antimatter. The celestial bodies and galaxies of which the universe consists represent matter. There are other theories which propose the presence of anti-stars and entire antigalaxies. They include cosmogonic concepts--an assumption concerning a certain initial *ambiplasma* (from the Greek word "ambios"--both), which consists of matter and antimatter. At a certain stage in the development

of the universe in powerful nonuniform gravitational and magnetic fields matter and antimatter separate without collisions between particles and antiparticles. Subsequent evolution includes annihilation processes which are appealed to in particular in explaining the powerful radiation of quasars.

Contemporary cosmology is characterized by its integral character. The problems noted of homogeneity, infinity, expansion, initial state in symmetry of the universe may be solved only within the framework of a unified picture. For example, the assumption concerning the separation of ambiplasma without particle collisions must somehow be reconciled with the high initial density of the universe in the initial state which results from the theory of an expanding universe. There are many such relationships and as a whole they exclude the possibility of the separate solution of fundamental astrophysical problems. These problems cannot be solved apart from the construction of the more general theory of elementary particles. At the same time such comparatively special problems, such as the nature of supernovae, the nature of quasars, etc., may be uniquely solved only in connection with the solution of fundamental problems.

/190

In contemporary astrophysics the Einstein requirement of "internal perfection" has become real to an unprecedented extent.

Such a requirement cannot be satisfied within the framework of the *classical* ideal of scientific explanation. This ideal consists of a reference to a certain plan of interacting discrete bodies as the last component of analysis. The new, nonclassical ideal of scientific explanation excludes the last components of analysis and is closer to the nonlinear concept of Spinoza concerning nature which interacts with itself and it introduces into science a concept concerning the interaction of fields and a self-consistent system of particles whose existence, rather than simple behavior, is the result of interaction. The new ideal of scientific explanation consists of the inclusion in the analysis of the *reality* of the universe of the existence of specific types of elementary particles and of the existence of space, structure and evolution which depend on the transmutations of particles and in turn determine the course of these transmutations.

A change in the ideal of scientific explanation has always proved to be a turning point in the development of civilization. What may the new, non-classical ideal of science give to civilization?

Cover Page Title

REFERENCES

1. Fridman, A. A., *Mir kak Prostranstvo i Vremya* [The Universe as Space and Time], p. 5, Second edition, Moscow, 1965.
2. Shklovskiy, I. S., *Vseleennaya. Zhizn'. Razum* [The Universe. Life. Reason.], pp. 41-51, Second edition, Moscow, 1965.
- Masevich, A. G., "Evolution of the Stars," In the reference book *Nauka i Chelovechestvo* [Science and Humanity], pp. 343-357, Moscow, 1964.
3. Ambartsumyan, V. A., "The Basic Problem of Cosmogony," Reference book *Budushcheye Nauki* [Future Sciences], pp. 92-100, Moscow, 1966.
4. Shklovskiy, I. S., *Vseleennaya. Zhizn'. Razum* [The Universe. Life. Reason.], pp. 52-65.
5. Novikov, I. D., "On the Final Fate of the Stars," In the reference book *Budushcheye Nauki* [Future Sciences], pp. 120-121, Moscow, 1948.

Translated for the National Aeronautics and Space Administration under Contract No. NASw-2037 by Techtran Corporation, P.O. Box 729, Glen Burnie, Maryland 21061.